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**U.S. ARMY MISSILE COMMAND**

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## ABSTRACT

The effects of boattail segments on the static stability characteristics of bodies of revolution have been studied experimentally. Normal force and center of pressure from tests were correlated on the basis of boattail geometry and Mach number. Reynolds numbers for the test were constant at approximately $0.5 \times 10^6$ per inch over a Mach number range of 0 to 5. Based on these data, the center of pressure of the boattail is approximately 50 percent of its length. The resultant correlations are presented.

# CONTENTS



# ILLUSTRATIONS

## LIST OF SYMBOLS

| | |
|---|---|
| $A$ | Reference area for coefficients $\left(\frac{\pi D^2}{4}\right)$ |
| $D$ | Reference diameter — cylinder |
| $D_B$ | Base diameter |
| $C_m$ | $\frac{\text{Pitching moment about base}}{QAD}$ |
| $C_N$ | $\frac{\text{Normal force}}{QA}$ |
| $C_{m_\alpha}$ | $\frac{dC_m}{d\alpha}$ — Rate of change in pitching moment — Coefficient with angle of attack |
| $C_{N_\alpha}$ | $\frac{dC_N}{d\alpha}$ — Rate of change in normal force — Coefficient with angle of attack |
| $\Delta C_{m_\alpha}$ | Incremental pitching moment component due to boattail |
| $\Delta C_{N_\alpha}$ | Incremental normal force component due to boattail |
| $L_B$ | Boattail length |
| $M_\infty$ | Free stream Mach number |
| $q$ | Dynamic pressure |
| Rn | Reynolds number |
| Xcp | Center of pressure |
| $\theta$ | Boattail angle |
| $\alpha$ | Angle of attack |

## 1. Introduction

The boattail has a significant effect on the static stability characteristics of missile configurations. Its primary purpose is to tailor the stability margin for minimum change through the Mach number range. And, if properly designed, it can reduce the drag coefficient, but only its effect on normal force and center of pressure will be considered here.

## 2. Test Conditions and Configurations

The Aerodynamics Branch has conducted a series of wind tunnel tests (at Aberdeen Ballistic Research Laboratory and Arnold Engineering Development Center) on boattail configurations to determine their effect on normal force and center of pressure of bodies of revolution. The pertinent test conditions were: Mach number from 1.75 to 4.5 (Aberdeen Ballistic Research Laboratory test) and 0.8 to 1.5 (Arnold Engineering Development Center test) and Reynolds numbers from $0.27 \times 10^6$ to $0.48 \times 10^6$ per inch (Figure 1). The test models (Figure 2) were designed to cover the geometry range most often used in high-speed missiles. All models were conical-shaped boattails with diameter ratios of 0.72 tc 0.86 and angles from 4 to 10 degrees.

## 3. Measuring Technique

Two measuring techniques were used for these tests. One, the complete model [Figure 2(a)] was mounted on a strain gage balance for measuring total model loads. Two, the aft section [Figure 2(b)] was mounted on a specially built strain gage balance to measure only the aft portion loads.

The first technique (model No. 1) was tested through the Mach range (0.8 to 4.5), both with and without boattail. Incremental normal force due to boattail was determined by subtracting the straight cylinder data from the boattail case with equivalent total length. Center of pressure of boattail force was calculated from pitching moment and normal force.

The second technique (models T0-T4) was tested at the Ballistic Research Laboratory for Mach numbers of 1.75 to 4.5. Incremental normal force and center of pressure (due to boattail) calculations are the same as above except that the measurements do not include forces on the forward portion (nose - cylinder) as in the first technique. Results from the second method should be more accurate because boattail effects are measured directly (small angles of attack only).

## 4. Data Analysis

Test data from the first technique (Configuration No. 1) has been published.[1] These data are correlated with the new data obtained from the second technique for measuring boattail forces. A typical set of the new basic data (models T0 - T4) is presented in Figures 3 and 4 to show the general trend of normal force coefficient $\left(C_N\right)$ and pitching moment coefficient $\left(C_M\right)$ with angle of attack. The pitching moment reference center is the boattail base, and the reference length is the cylinder diameter.

The incremental normal force and pitching moment due to boattail was derived from experimental data using the following equations:

$$\Delta C_{N_{BT}} = C_{N_{W/BT}} - C_{N_{W/0\ BT}} \tag{1}$$

$$\Delta C_{M_{BT}} = C_{M_{W/BT}} - C_{M_{W/0\ BT}} \tag{2}$$

$$Xcp_{BT} = \frac{\Delta C_{M_{BT}}}{\Delta C_{N_{BT}}} \tag{3}$$

The boattail normal force and center of pressure was correlated on the basis of geometry and Mach number for all cases tested. Several approaches were tried for the normal force correlation, such as basing the coefficient $\left(C_N\right)$ on boattail planform area rather than cylinder cross-sectional area. However, none of the approaches showed any improvement over the correlation presented (Figure 5).

The pitching moment near zero angle of attack was scattered for most cases; however, sufficient data were available to show the general trend of center of pressure changes with Mach number. The center of pressure, in percent of boattail length, is presented in Figure 6.

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[1]Washington, William D., Conical Boattail Effects on the Static Stability Characteristics of Bodies of Revolution, U.S. Army Missile Command, Report No. RD-TN-67-1, January 1967.

## 5. Results and Conclusions

The normal force and center of pressure for boattail segments have been correlated using experimental data.

The normal force correlation (Figure 5) is a function of boattail geometry and Mach number. Munk's theory[2] is presented for comparison at subsonic speeds. No attempt was made to evaluate Reynolds number effects outside the range tested ($0.27 \times 10^6$ to $0.48 \times 10^6$ per inch).

Center of pressure in percent of boattail length is plotted versus Mach number in Figure 6. A part of the pitching moment data was not conclusive, because of scatter near zero angle of attack; but the data used indicate that the center of pressure is near 50 percent of the boattail length.

Additional tests are needed through the subsonic and transonic range to substantiate the normal force and center of pressure correlations. Also, Reynolds number effects should be investigated over a wide range throughout the Mach number regime.

[2]Munk, Max M., The Aerodynamic Forces on Airship Hulls, National Aeronautics and Space Administration, Report No. 184, 1924.

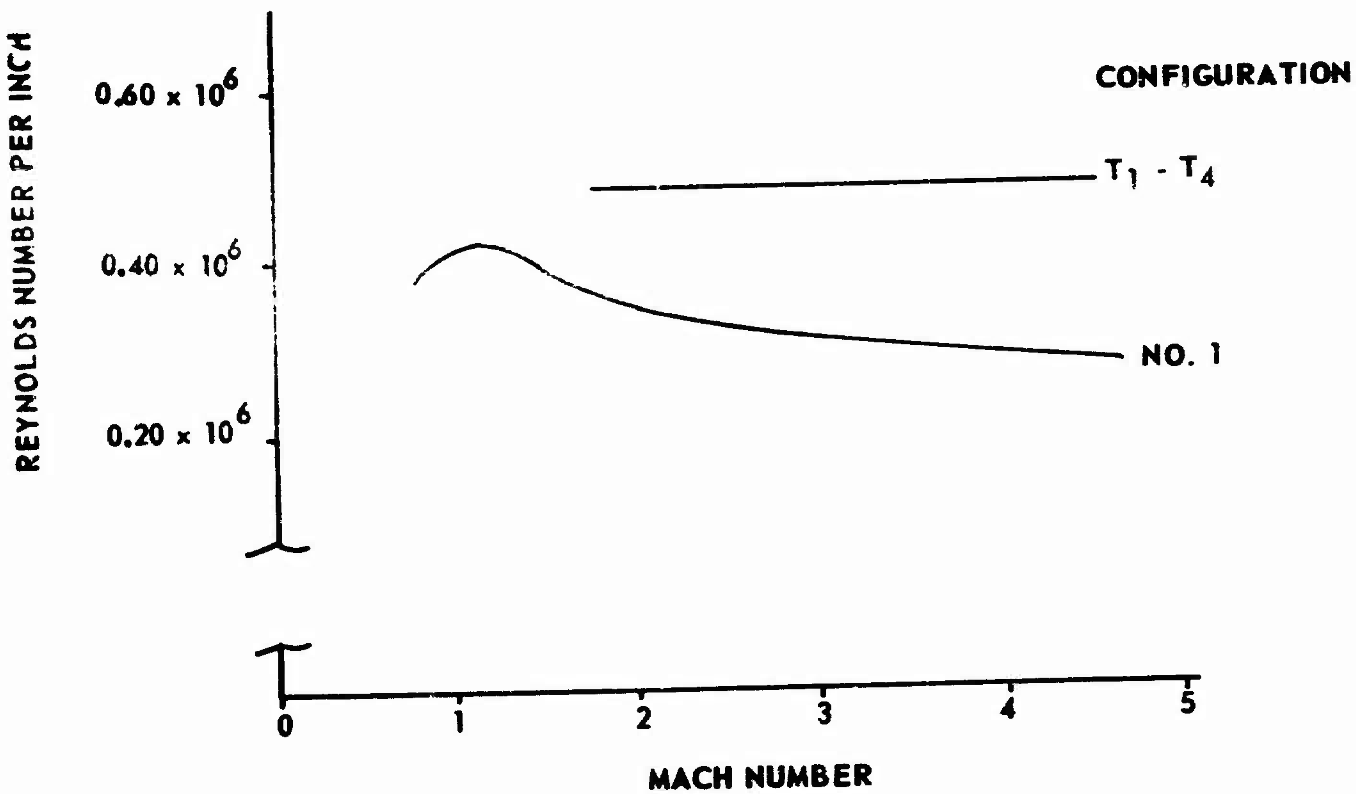


FIGURE 1. TEST REYNOLDS NUMBER PER INCH

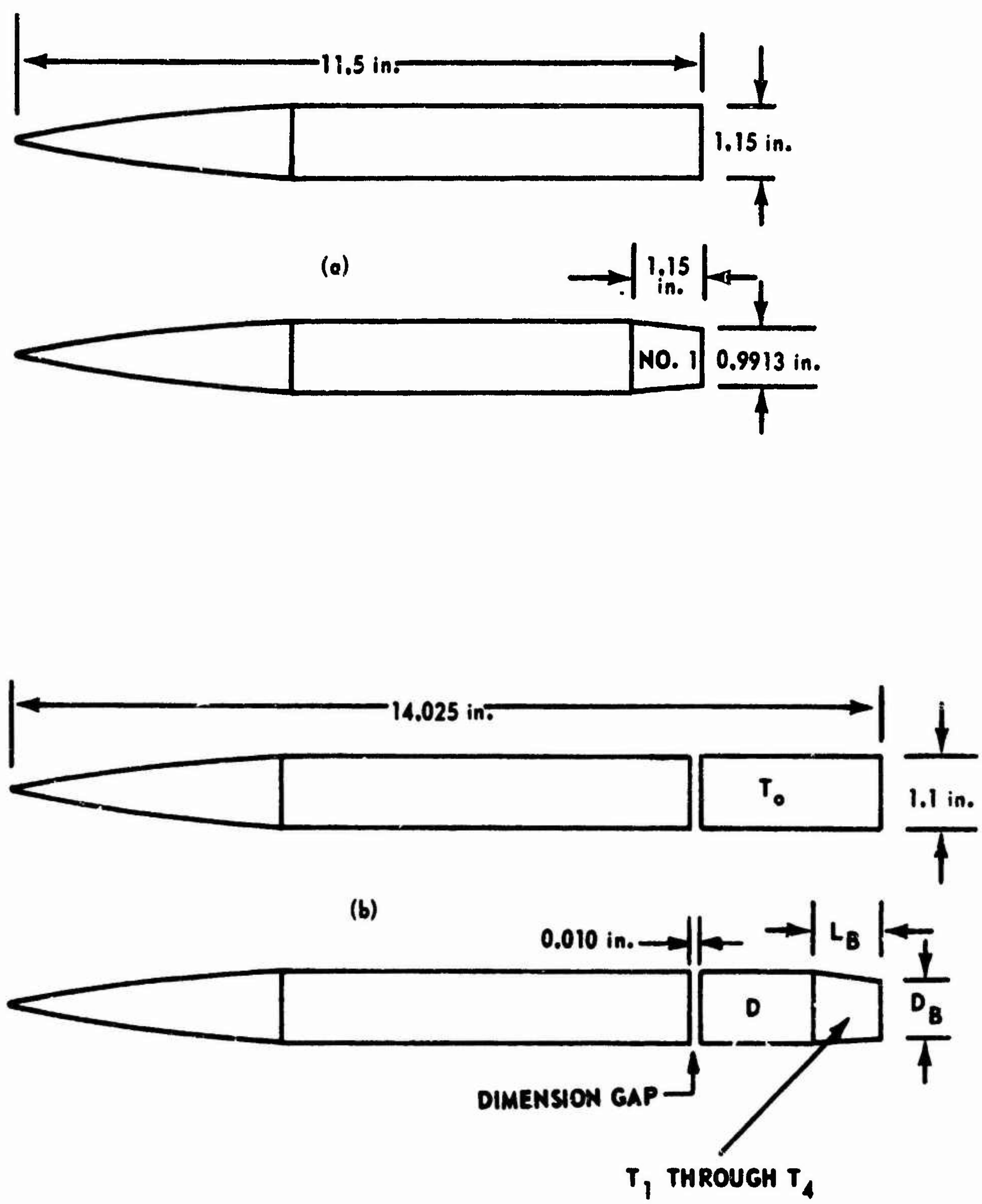


FIGURE 2. CONFIGURATIONS

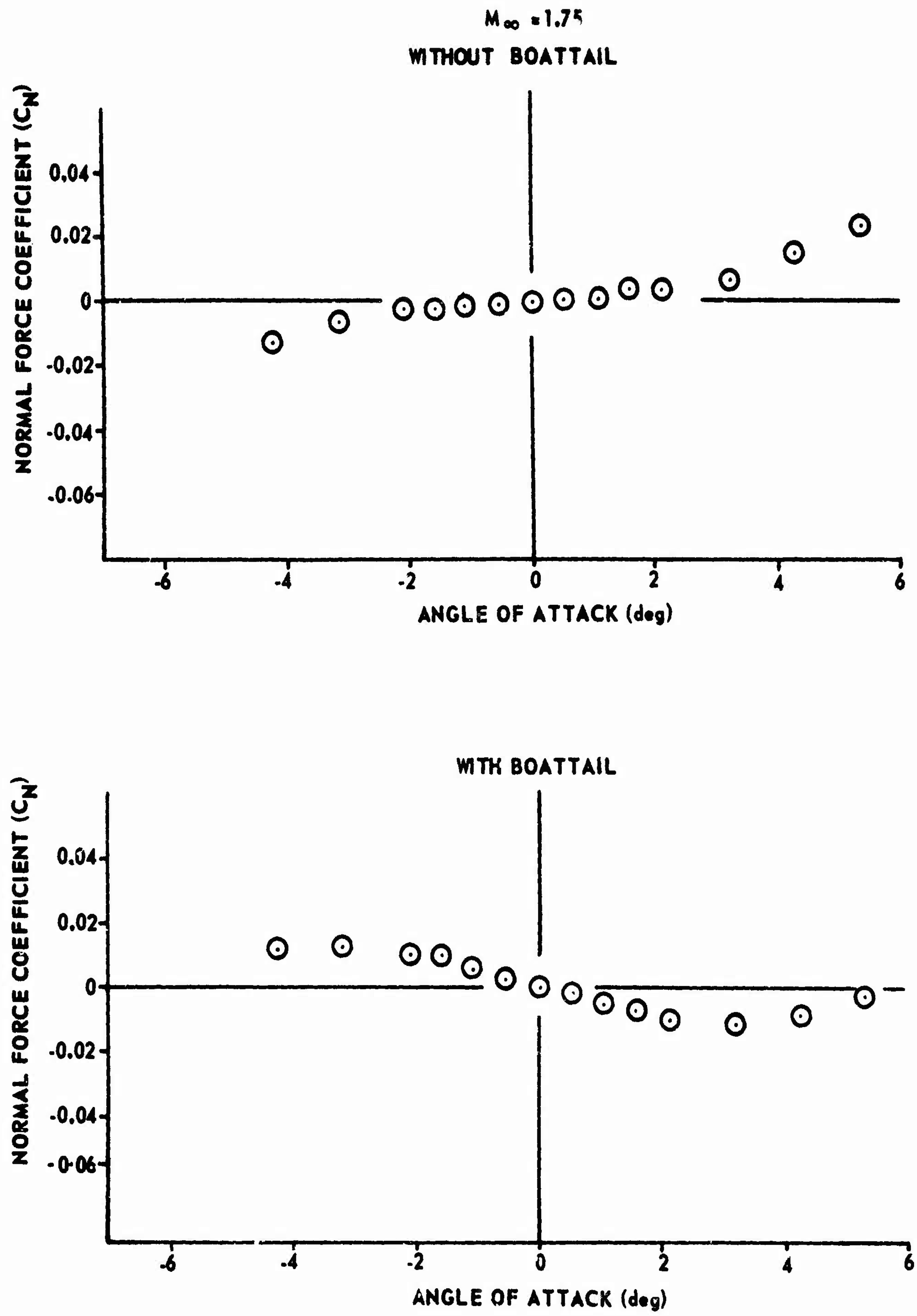


FIGURE 3. TYPICAL NORMAL FORCE VERSUS ANGLE OF ATTACK

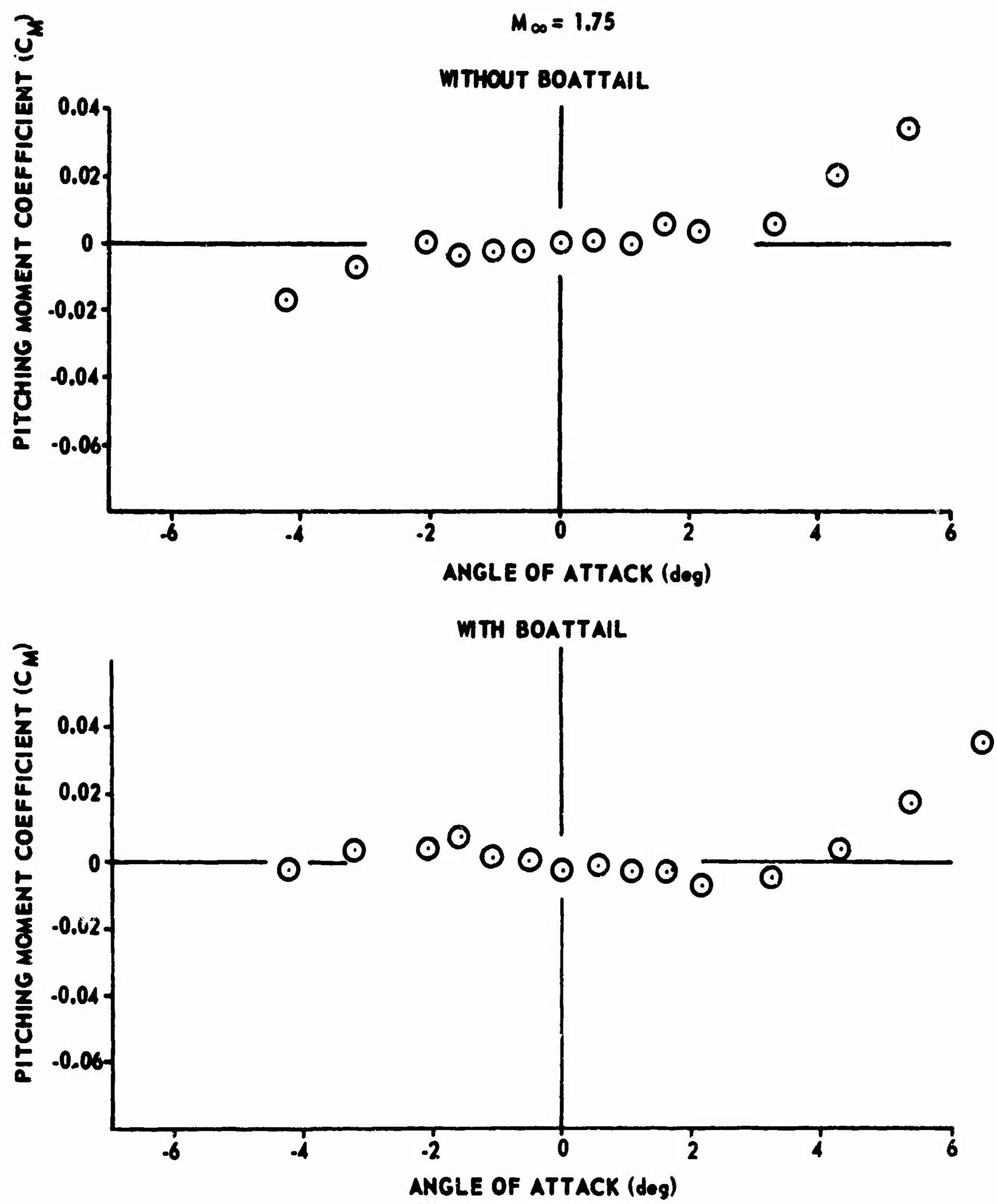


FIGURE 4. TYPICAL PITCHING MOMENT
VERSUS ANGLE OF ATTACK

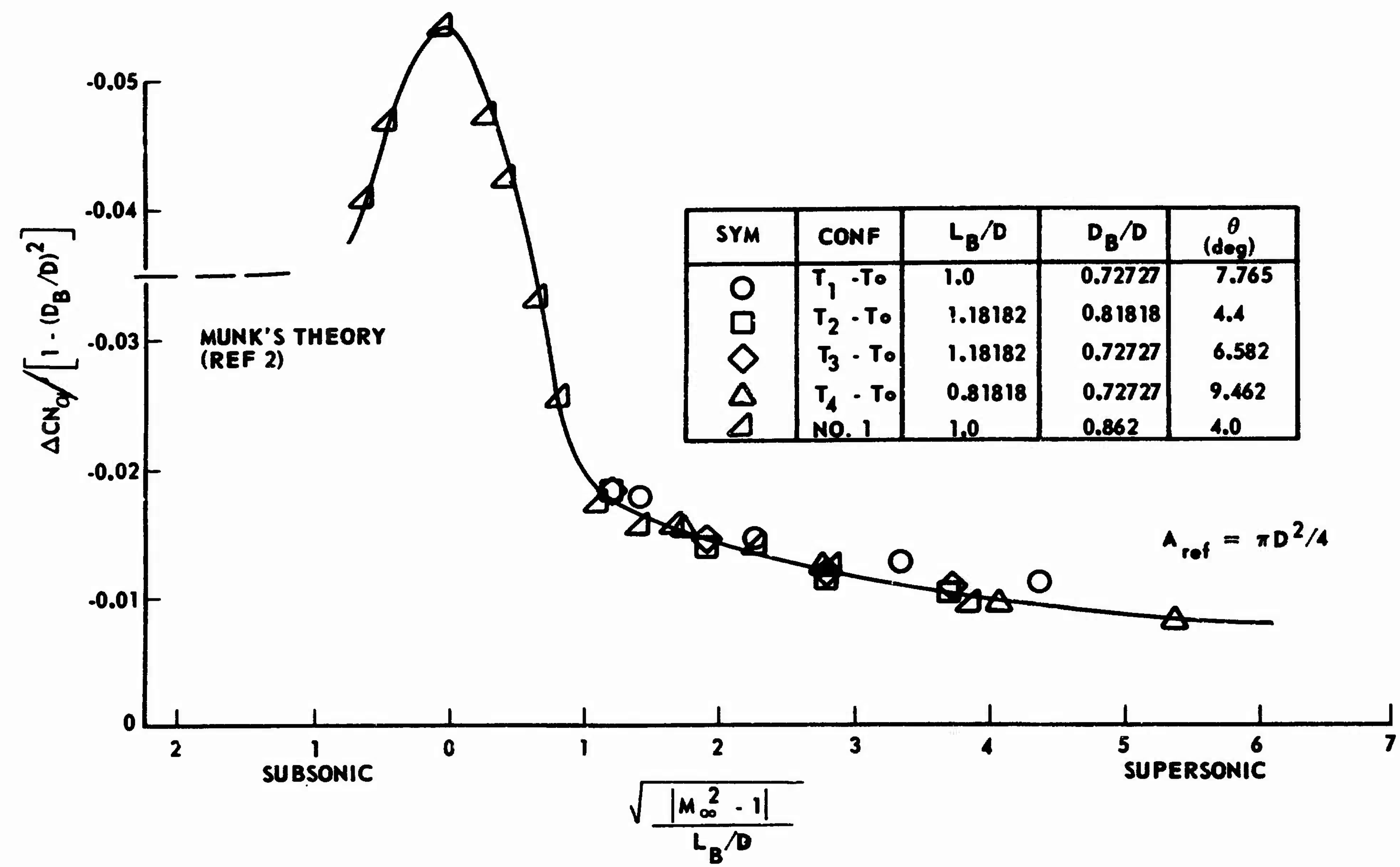


FIGURE 5. BOATTAIL NORMAL FORCE CORRELATION

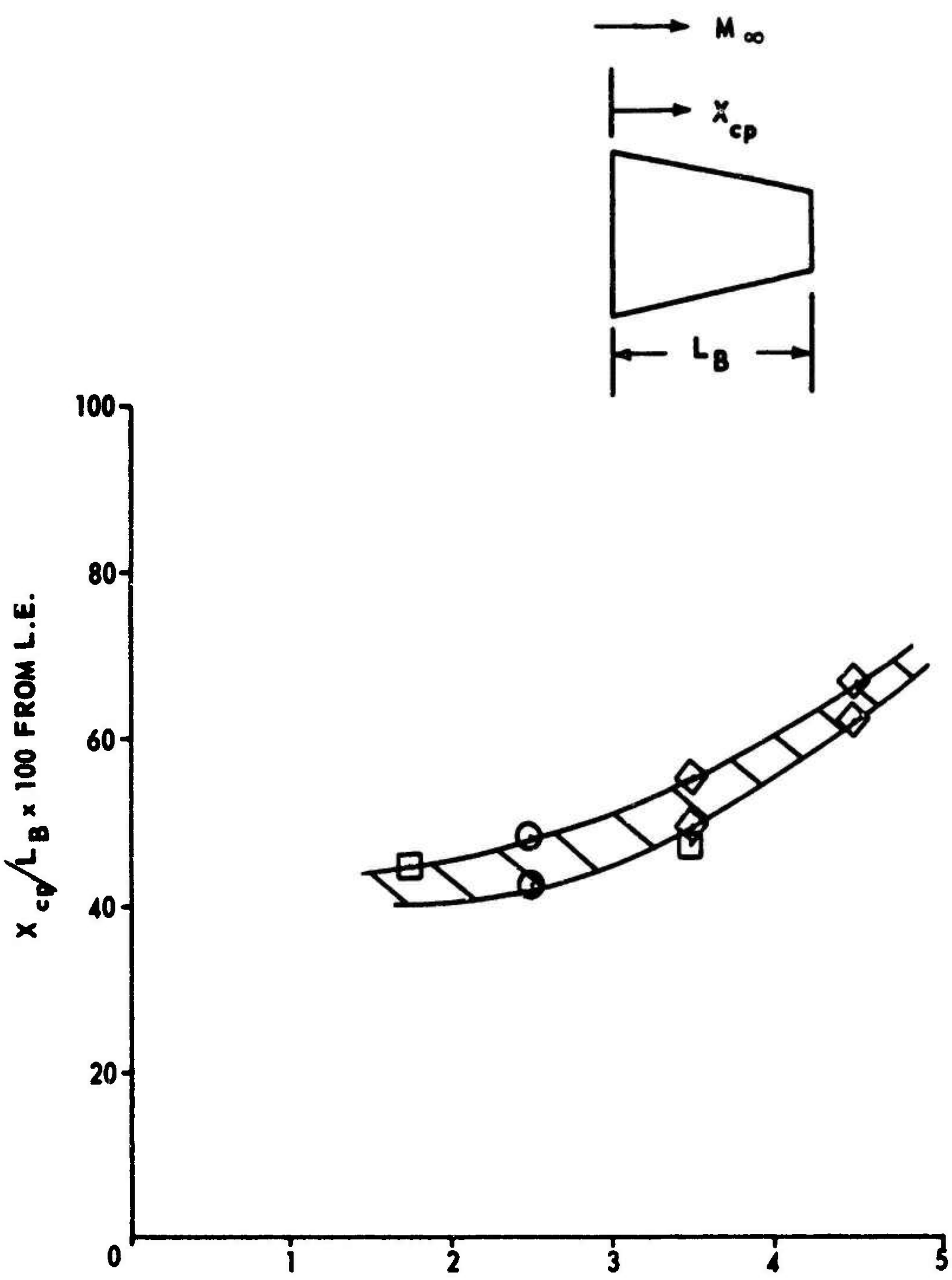


FIGURE 6. BOATTAIL CENTER OF PRESSURE